METHOD FOR CATALYZING OXIDATION/REDUCTION REACTIONS OF SIMPLE MOLECULES

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This application is a continuation of application Ser. No. 07/328,802, filed on Mar. 23, 1989, now abandoned, which is a continuation of application Ser. No. 07/179,981 filed Apr. 11, 1988, now abandoned, which is a divisional of application Ser. No. 06/648,952 filed Sept. 10, 1984, now U.S. Pat. No. 4,751,068.

BACKGROUND OF THE INVENTION

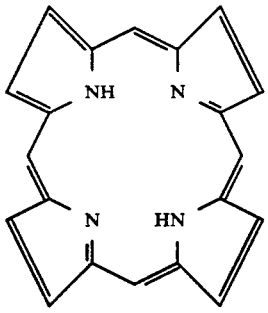
1. Field of the Invention

This invention relates to a method for catalyzing oxidation/reduction reactions based on polydentate nitrogen-containing chelating agents complexed with a metal atom.

(It must be noted that there is no universal agreement on the definition of "catalyst" or "catalyzing". Definition of the term "catalyst" varies depending on the art, for example, as between the fundamental investigator and the practitioner, and among researchers concerned with heterogeneous catalysis, homogeneous cataysis, polymerization reactions, and enzymes. In the present application a "catalyst" is defined as a substance that increases the rate of reaction and which may be regenerated or returned to its original state if it is transformed as the result of a catalytic reaction.)

2. Description of the Prior Art

The better known and studied catalytically active polydentate nitrogen-containing compounds are porphine-like molecules and their relatives (e.g., porphyrins). Porphine possesses a basic macrocyclic tetrapyrrole structure, illustrated below.



In many instances, porphine-based prosthetic groups are tightly or covalently bound to an apoenzyme, and complexed to an iron atom. In other instances Mg, Zn, Ni, Co, or Cu may be complexes to these porphines.

Proteins containing porphine-based prosthetic groups are known to perform diverse roles. They reversibly bind dioxygen for transport (hemoglobin and myoglobin), transfer electrons one at a time in membraneous respiratory chains (cytochromes), reduce peroxides (catalases and peroxidases), and act as terminal components in multi-enzyme systems involved in hydroxylation.

The catalytic functions of iron/porphine-proteins based on their metal centers are known. Two oxidation states of iron —Fe^{2+} and Fe^{3+}—are known to be stable in aqueous solutions. These are the major redox forms of iron proteins.

The cytochromes are a group of iron-containing electron transferring proteins that act sequentially to transfer electrons from flavoproteins to oxygen. They all contain iron-porphine prosthetic groups. The cytochromes undergo reversible Fe^{+2}–Fe^{+3} valence changes during their catalytic cycles. At least six types of cytochromes have been identified : cytochromes b, b_5, c, c_1, a, and a_3. These cytochromes are primarily differentiated by their different reduction potentials.

The hydroperoxidases are ferri-(Fe^{3+})-hemoproteins which have as preferred sustrates H_2O_2 (catalases) or alkyl peroxides (peroxidases). These enzymes act to oxidize phenols, aryl and alkyl amines, hydroquinones, ascorbate, cytochrome c, or glutathione.

In hemoglobins and myoglobins the iron atom does not undergo changes in valence as oxygen is bound or lost; it remains in the Fe^{+2} state. Both hemoglobin and myoglobin can be oxidized, however, to the Fe^{+3} forms, which are known as methemaglobin and metmyoglobin respectively.

Carbon monoxide combines with hemoglobin to form CO-hemoglobin. Each heme in hemoglobin can bind one carbon monoxide molecule but O_2 and Co cannot simultaneously bind to the same heme. The binding affinity for CO is about 200 times greater for carbon monoxide than for oxygen. Adventitious CO occupation of the heme position of a hemoglobin inactivates the heme.

It is known that when cytochrome c oxidase in the ferric, Fe^{+3}, form is stored under an atmosphere of carbon monoxide, the heme iron of cytochrome a_3 will become reduced to Fe^{+2} and then bind CO. This reduction, accomplished under a Co atmosphere in the absence of other reactants, has been referred to as "autoreduction".

Young and Caughey (*Fed. Proc.*, 1980, 39, 2090 (Abstract 2562)) have demonstrated that ^{13}CO is oxidized to $^{13}CO_2$ by cytochrome c oxidase and O_2. This study also reveals that with $^{18}O_2$, ^{18}O is incorporated into the CO_2 product. On this bases, Young and Caughey have suggested that the oxidation of CO to CO_2 occurs via the following reaction:

$$\tfrac{1}{2}O_2+CO\rightarrow CO_2.$$

Thus, although no accepted mechanism explaining how "autoreduction" occurs exists, the heme mediated oxidation of CO has been proposed to proceed via one of the two following pathways:

1) Young and Caughey have suggested that the reaction is a concerted process, occurring with dioxygen and two molecules of CO so that each O atoms from the dioxygen molecule ends up in the CO_2 molecules produced.

2) Bickar, Bonaventura and Bonaventura (Biophysical Society Annula Meeting, 1982, Feb. 14–17, Boston, MA) have suggested that the reaction is a two step process which consists of an initial reduction of cytochrome c oxidase by CO releasing CO_2, followed by the oxidation of cytochrome c oxidase by O_2.

SUMMARY OF THE INVENTION

In accordance with the present invention, it has now been discovered that catalyst systems based on one or more polydentate nitrogen-containing chelating agents (herein after simply referred to as chelating agent) com-